On Fuzzification of Color Spaces for Medical Decision Support in Video Capsule Endoscopy

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Abstract

Advances in image and video processing algorithms and the availability of computational resources has paved the way for real-time medical decision support systems to be a reality. Video capsule endoscopy is a direct imaging method for gastrointestinal regions and produces large scale color video data. Fuzzification of color spaces can improve contextual description based tasks that are required in medical decision support. We consider abnormalities detection in video capsule endoscopy using fuzzy sets and logic theory on different colorspaces. Application in retrieval of bleeding detection and polyp vascularization are given as examples of the methodology considered here and preliminary results indicate we obtain promising retrieval results.

Introduction

Video capsule endoscopy (VCE) is a revolutionary imaging technique which paved the way for unprecedented direct visualization of the gastrointestinal tract without much discomfort to patients. A typical colon VCE exam produces around 8 hours of color (RGB) video data. For example, Pillcam Colon capsule endoscope (Given Imaging, Yoqneam, Israel) produces approximately $30,000$ frames per patient and more than 1.6 million patients worldwide have used capsule endoscopy over the past 10 years. Automatic algorithms can help augment computer aided diagnosis (CAD) in VCE medical decision support systems and can help reduce the burden on gastroenterologists (Rey 2008; Niwa et al. 2008). For example, polyp detection (Figueiredo et al. 2010; 2011), mucosa surface identification (Prasath, Figueiredo, and Figueiredo 2011; Prasath et al. 2012; Prasath and Delhibabu 2015b), contrast enhancement (Prasath and Delhibabu 2015a). Nevertheless, designing automatic methods for automatically analyzing the VCE imagery via image processing and computer vision techniques pose significant challenges as we are dealing with big data.

Image processing involves uncertainty quantification and fuzzy techniques are effective in handling various tasks (Kerre and Nachtegael(eds) 2000; Vlachos and Sergiadis 2006; Shamoi, Inoue, and Kawanaka 2014b; 2014a). Recently, Shamoi et al (Shamoi, Kawanaka, and Inoue 2014) used fuzzification of HSI color space for apparel coordination. In (Shamoi, Kawanaka, and Inoue 2014) a case example in HSI (Hue, Saturation, Intensity) space is provided for obtaining a correspondence between colors and human impressions. In this work, we adapt the ground-work done in (Shamoi, Kawanaka, and Inoue 2014) to the VCE color space fuzzification for abnormality classifications. We provide an overview of different color spaces (RGB, CMYK, HSV, La*b*) and their fuzzifications to organize all possible human operator color perceptions of abnormalities in VCE images. Using operator defined impressions expressed in terms of linguistic terms we provide retrieval examples. We note the overall framework is general in the sense that it can be expanded with domain knowledge for various related tasks.

The rest of the paper is organized as follows. Next section introduces different color spaces useful in VCE imagery and fuzzification techniques for representing color perceptions of human operators using fuzzy sets. Next, we provide some example classification results on VCE images for bleeding regions.

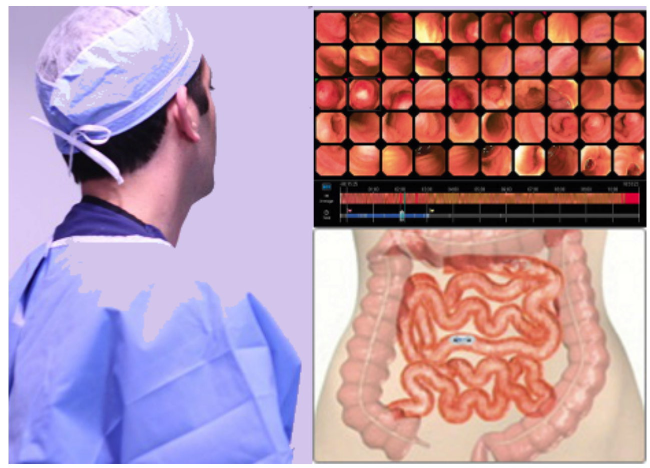


Figure 1: Each VCE exam involves a human operator (gastroenterologist) looking at various abnormal frames and classifying the impressions using linguistic terms. Automatic classification using a mapping of such linguistic terms to colors using fuzzy logic can be used for various tasks such as image retrieval.

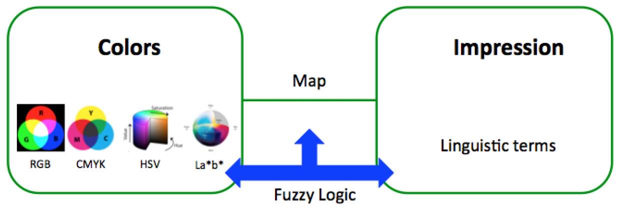


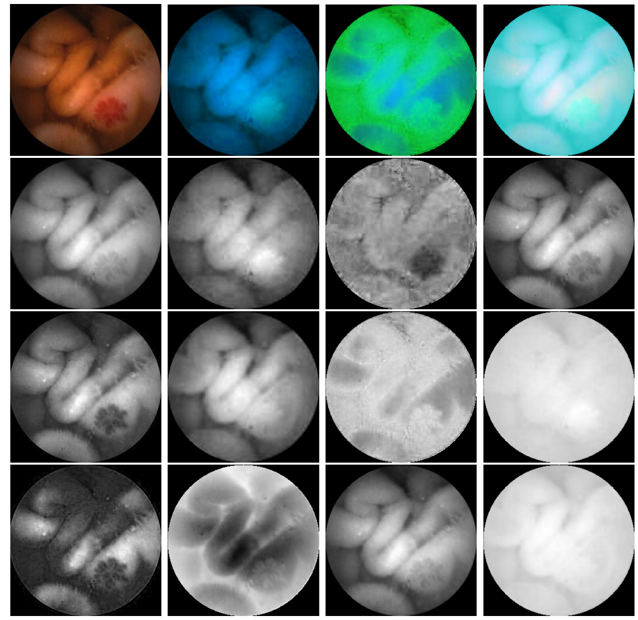
Figure 2: Fuzzy logic and mass assignment theory based mapping of different colors and human (operator) impressions of them. Image adapted from (Shamoi, Kawanaka, and Inoue 2014).

Color Fuzzification for Abnormalities in video Capsule Endoscopy

Fuzzification

Appearance of different abnormal regions such as polyps, adenomas, and bleeding in VCE videos under different color spaces provide different linguistic terms for description. This can be utilized in the fuzzy logic framework advocated in (Shamoi, Kawanaka, and Inoue 2014), see Figure 2. All three components of a medical decision system, namely, different color spaces, impressions based on linguistic terms, and mapping between them, are all interpretable using fuzzy logic. In particular we consider an example of bleeding detection in VCE, see Figure 3. Note that various color spaces can be utilized in the fuzzification framework and we consider standard color spaces such as RGB, CMYK, HSV and La*b*, we refer to (Wyszecki and Stiles 1982) for corresponding definitions and formulae. Each give a different perspective of an abnormality, see Figure 3 for an example of bleeding region in RGB, CMYK, HSV and La*b* spaces. Advantages of color (spectral) information can be exploited for different diagnostic decision purposes (Figueiredo et al. 2011; Prasath and Delhibabu 2015a). In this particular case of bleeding detection, gastroenterologists tend to mark bleeding regions using linguistic terms such as dark red/medium red or pale red. For example, in RGB color space (see Figure 3(a)) the bleeding region is darker in green and blue channels and the overall appearance can be characterized as dark red in the RGB spectrum. Thus, fuzzy logic and mass assignment theory based mapping of different colors and human (operator) oriented impressions can be utilized in making a medical decision support system.

Figure 4 shows RGB and HSV fuzzy sets which are used to fuzzify different bleeding regions. In contrast to the apparel coordination application considered in (Shamoi, Kawanaka, and Inoue 2014), here we use only RGB color space and the Value (from HSV) fuzzy membership functions. Hence, the {Red, Green, Blue} and {Dark, Medium, Pale} are the spectral and linguistic terms, respectively. We utilized a ground truth marked histogram from two experienced gastroenterologists for various bleeding regions and Figure 6 shows some examples with Red and three linguistic terms. Context dependent color impressions in the bleeding scenario are *light, strong* which indicate lighter or stronger bleeding regions respectively. Note that for different tasks these context dependent color impressions are utilized as a query, for example light bleeding (see Figure 5(a)).



(a) RGB (b) CMYK (c) HSV (d) La*b*

Figure 3: Different color spaces can be utilized in identifying abnormalities in VCE exams. In this example, a bleeding region (from a Pillcam® Colon capsule image) is visualized in different color spaces and the proposal in this paper can play a crucial rule in medical decision support system for VCE. First row shows RGB, CMYK, HSV, La*b* images and next rows their corresponding individual channels. For CMYK space, we only show magenta, yellow, key images and omit cyan as it did not provide any visual information in this example.

Retrieval

Following (Shamoi, Kawanaka, and Inoue 2014) we utilized a taxonomy of color impressions adapted for VCE imagery based medical decision support systems. Here we describe it for bleeding regions and Table 1 provides the taxonomy of color impressions in the RGB - Value case, and a similar table is generated for the polyp vascularization with RGB - Density. Using these taxonomy we follow basic formulae in fuzzy logic such as the intersection (minimum), union (maximum) of two membership functions,

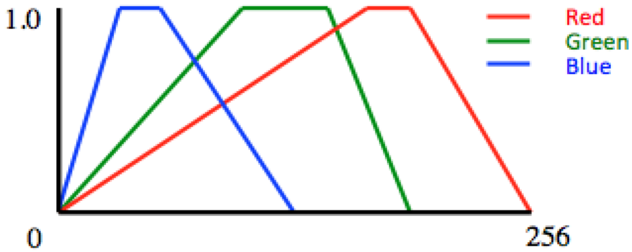
$$(\mu A \cap \mu B)(x) = \min\{\mu A(x), \mu B(x)\}$$

$$(\mu A \cup \mu B)(x) = \max\{\mu A(x), \mu B(x)\}$$

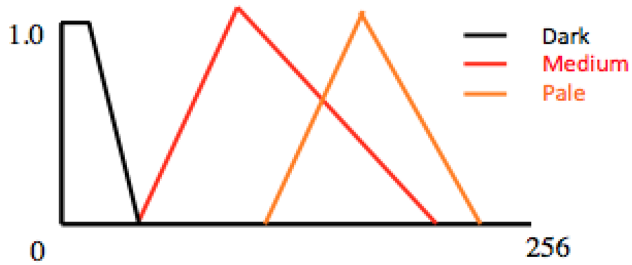
and α-cut

$$f_\alpha = \{x : \mu_f(x) \geq \alpha\}.$$

These basic fuzzy formulae are used to fuzzify color spaces and interprets linguistic impressions of colors for composite cases. We used these formulae along with a map between



(a) RGB



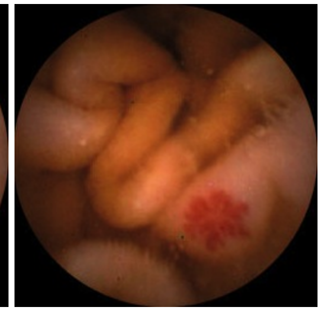
(b) HSV - Value

Figure 4: Example fuzzy sets for color spaces RGB and HSV based on linguistic labels in bleeding regions classification in VCE. Note for the HSV space we only show the Value channel.

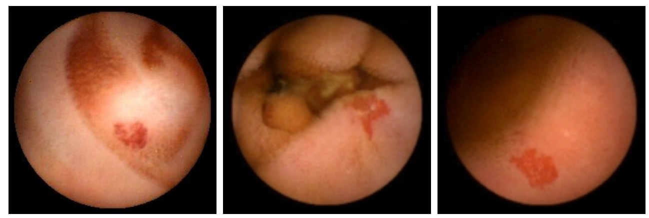
color impressions and color in RGB, Value in ranking similar images for bleeding region identification.

Similar interpretations are done in the polyp vascularization and *density, tortuosity* are used as context dependent impressions. Figure 5 provides example results in bleeding and polyp vascularization using linguistic queries alone. Figure 6 shows the corresponding ranking mechanism based on linguistic impressions for the bleeding the vascularization cases. As can be seen, histograms are utilized to identify the top three ranked nearest images matching the *Dark red* interpretation and the retrieval results are accurate as per gastroenterologist ground truth markings. All the retrieved bleeding regions are from the jejunum area of the gastrointestinal tract and we only show top three results according to color histogram matching, see Figure 6(a). A similar analysis with RGB space and polyp vascularization *density* is undertaken and the the query image (Figure 5(d)) is described as *Pale Red Dense* and the ranking given in Figure 6(b) ranks the resultant images according to the density of vascularization. All the retrieved vascular regions contain dense vessels and are malignant. We utilized 400 Pillcam® Colon capsule images for bleeding detection, these were obtained from 5 different patients, and marked by two gastroenterologists who provided ground truth regions along with boundaries separating bleeding from normal mucosa tissue. For polyp vascularization based retrieval we used 100 images which are benchmarked against an automatic segmentation method (Prasath, Pelapur, and Palaniappan 2014) for calculating the density of vascularization in polyps.

(a) Input

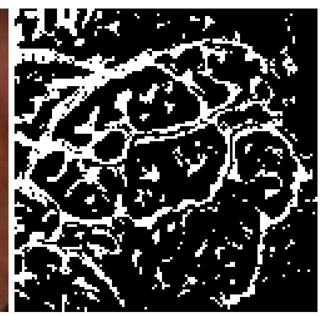


(b) Groundtruth

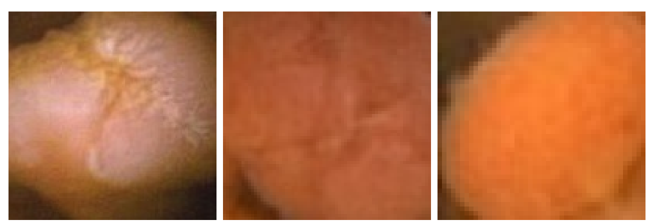


(c) Bleeding

(d) Input



(e) Groundtruth



(f) Polyp vasularization

Figure 5: Two example results in bleeding and polyp vascularization. (a): For a given input image of bleeding spot which is described as (b) *Dark Red* the system retrieves similar images containing bleeding regions with (c) decreasing ranks (matching). (d): For a given input polyp image which is described as (e) *Dense tortuous* the system retrieves similar polyp images with (f) decreasing density. Note we only the top three retrieval results and the ground truth regions are marked by human (operators) and used in training the impressions and their mappings.

Table 1: Taxonomy of color impressions in the RGB case for bleeding regions in VCE images.

Level	Impressions	Comment
I	Red, Black	Atomic context independent colors
II	Dark, Medium, Pale	Atomic context independent, dependent colors
III	Combinations of I & II	Composite context independent, dependent colors

Conclusion

In this paper, we considered fuzzification of different color spaces for medical decision support systems in gastrointestinal diagnosis using video capsule endoscopy. Following (Shamoi, Kawanaka, and Inoue 2014) we utilized fuzzy sets and logic, color space theory for VCE imagery interpretation and used it for retrieval tasks. Our preliminary results in bleeding region detection and polyp vascularization in various VCE images indicate promise for using fuzzification techniques in a medical decision support system. Future works include introducing shape (e.g. polyp appearance), texture (e.g. pit patterns) features along with fuzzification framework studied here for different VCE videos. Moreover, increasing the number of experts (in our case study gastroenterologists) and quantifying/enlarging the linguistic impressions is an important avenue to be explored. We also believe the framework considered here will help in identifying trash, bubbles for uninformative frame classification.

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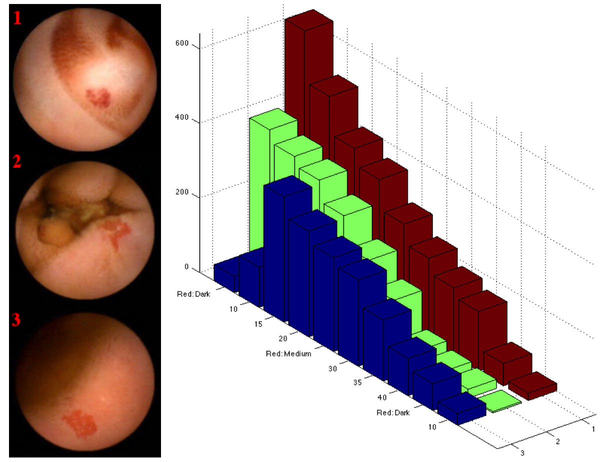
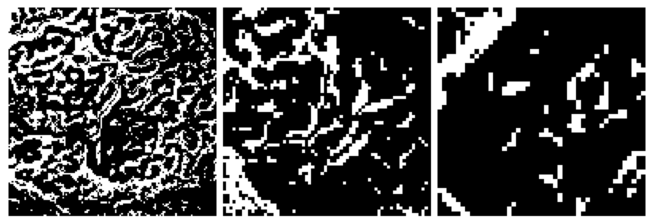


(a) Bleeding



(b) Polyp vascularization

Figure 6: Ranking based on linguistic terms and (a) color histograms in the bleeding region identification (b) Density of vascularization in the polyps in decreasing order.

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